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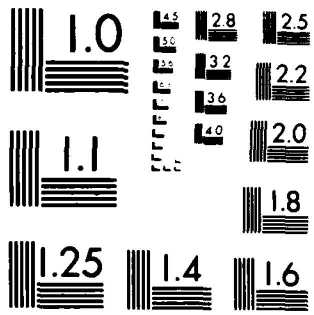

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THE HIERARCHY OF MOTION SYSTEMS OVER LARGE PLATEAUS

by
Elmar R. Reiter, Maocang Tang and
Rujin Shen

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TABLE OF CONTENTS

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THE HIERARCHY OF MOTION SYSTEMS OVER LARGE PLATEAUS

by

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ABSTRACT

Motion systems of various scales are caused by the differential heating of plateaus and the surrounding plains. On the largest scales, monsoonal systems and their interannual variability are considered. Comparisons are made between the effects of the Western Plateau of North America and of the Plateau of Tibet. Synoptic-scale systems are strongly affected by the plateaus of the northern hemisphere. An example of cyclogenesis over Eastern Tibet is given through a numerical model experiment. Diurnal heating effects of the Western Plateau of North America cause a large-scale "plateau circulation system" to develop. This system has a decisive impact on the diurnal variability of thunderstorm activity over the plateaus and over the plains to the east. It is shown that local heating and cooling by detailed topographic features can interact with the diurnal plateau circulation system.

1. INTRODUCTION.

Large plateaus and mountain ranges not only exercise a barrier effect on atmospheric flow processes, but constitute elevated heat or cold sources which generate baroclinicity that results in a variety of circulation systems. Depending on the space and time scales over which these baroclinic processes are effective we can distinguish a hierarchy of evolving circulation systems. These systems interact with each other, sometimes in a way which makes it difficult to assess from diagnostic studies the separate impacts of any one scale.

The longest time scales which we will consider here are concerned with seasonal, or monsoonal variability. The thermal effects of the northern hemisphere plateaus, on this scale, interact with the seasonal variability of the global general circulation.

Even within the monsoonal time scale one can distinguish mesoscale, quasi-permanent pressure systems over Tibet and over the Western Plateau of the United States. These pressure systems appear to be tied to prominent features in the topography (Reiter, 1982) and have a strong impact on regional climate characteristics, such as the frequent formation of convective precipitation systems, or the prevalence of desert conditions.

The interannual variability of the general circulation impacts on these monsoon systems, but so do the transient, synoptic disturbances, the sum total of which constitutes the seasonal climate. These disturbances, having a time scale of a few days, are strongly affected by topographic features and their associated surface heat budget distributions.

A major impact of these synoptic systems comes from the diurnal variability of the heat source and sink distributions over the large plateaus. A large, diurnal plateau circulation system can be identified theoretically as well as diagnostically, having a space scale of the order of 10^3 km, and a time scale of 24 hours. This circulation system undergoes monsoonal (seasonal) changes, but should not be confused with the monsoon system as such.

Finally, there are local wind systems, such as mountain and valley breezes, which operate on relatively small space scales and on a diurnal time scale. They are affected by the plateau circulation system, the monsoonal system, and the synoptic systems.

The enumeration of these systems in a hierarchical order of space and time scales seemingly implies linear interactions, directed from larger to smaller scales. Such an implication might grow even stronger in the subsequent, more detailed description of some of these systems. We should emphasize, therefore, that all these interactions, a priori, have to be assumed as nonlinear. We will have to allow for the fact that local, diurnal scales can influence regional and large scales of longer duration. It is only our inadequate analytical and numerical modeling techniques which impose a preference of down-scale forcing.

2. THE MONSOONAL SCALE.

It is impossible to separate in diagnostic studies the seasonal changes of the global, or hemispheric, general circulation from changes brought about solely by the thermal effects of the large plateaus. As these plateaus undergo their annual heating and cooling cycles the planetary wave configurations change accordingly and produce changing aspects of the wind fields over the plateaus, thus altering the dynamic plateau effects. Reiter and Westhoff (1981) have shown that the interannual variability of the ultralong planetary waves (wave Nos. 1 and 2) are subject to the largest interannual variabilities in the latitude ranges and seasons in which the major, northern hemisphere plateaus change their character between heat and cold sources (see e.g. Ye, 1982). Figure 1 shows the ratio between planetary wave amplitudes computed from the long-term mean 500-mb height distributions, and the same amplitudes computed daily, and then averaged according to calendar date irrespective of the phase position of the waves. The results thus obtained become a measure of the interannual variability of these planetary waves. A value of 1.00 in Fig. 1 would indicate a perfect recurrence of wave position each year at the same time, whereas a value of 0.00 would stand for random variability of wave positions. Waves 1 and 2 appear to be strongly affected, at monsoonal time scales, by plateau and continental heat source characteristics, although oceanic temperature anomaly effects cannot be ruled out as a cause for interannual planetary wave variability.

Most numerical modeling studies have concerned themselves with the variability of sea-surface temperatures (SST) as a possible, long-acting perturbation mechanism (see e.g. Julian and Chervin, 1978; Hanna et al., 1984, and many other theoretical and diagnostic studies). Since little is known about the interannual variability of the intensity of the Tibetan and North American heat sources and sinks, we are not yet in a position to simulate the effects of such variations on monsoon circulations. Suggestions have been made by Hahn and Shukla (1976) and Chen and Yan (1978) that the interannual variability of snow cover in Tibet might be the cause for variability in the Indian monsoon circulation. Reiter and Ding (1980/81) have pointed out that the snow cover in Tibet might be tied to circulation anomalies which are linked to anomalous SST distributions in the Atlantic and/or Pacific Oceans. Obviously, a challenging problem awaits us in resolving this question. A solution will, undoubtedly, have a significant impact on the skill of long-range (seasonal) forecasts. Its achievement requires close coordination between the acquisition and analysis of a useful data base and the execution of numerical models suitable for climate studies.

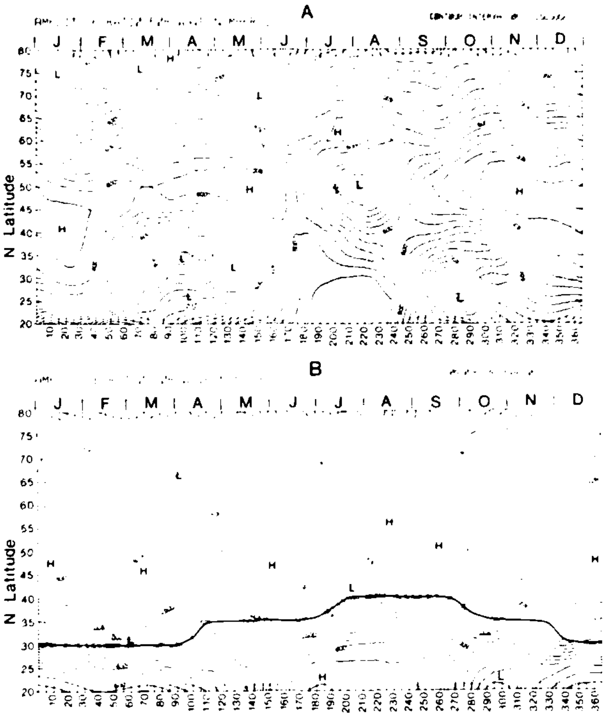
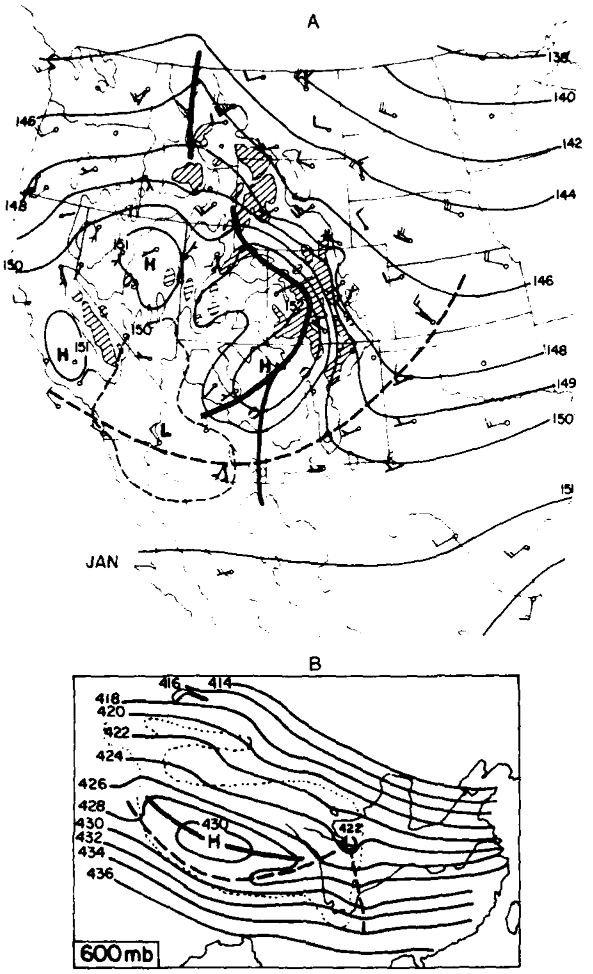


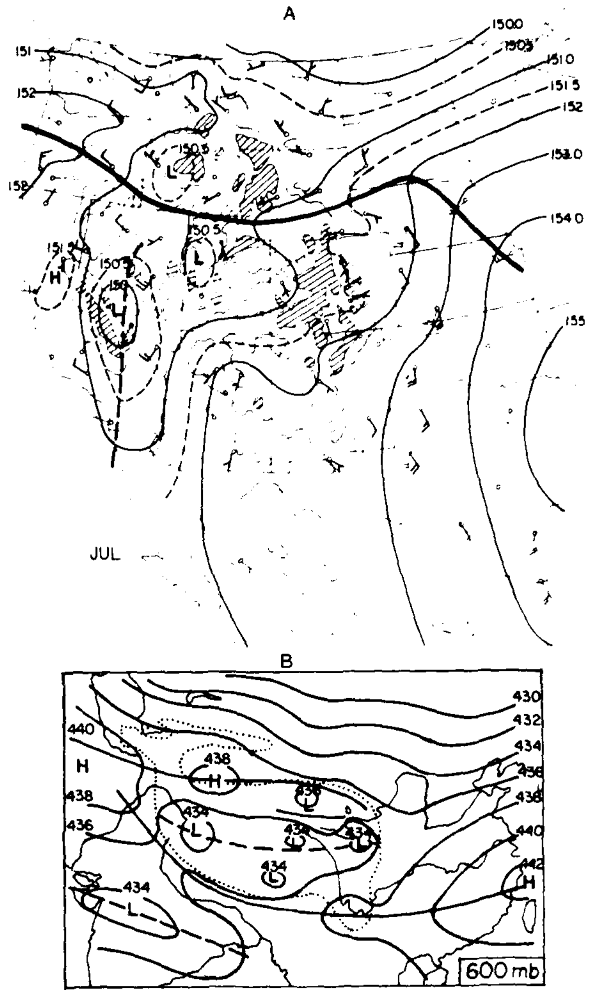
Fig. 1 Ratio between planetary wave amplitudes computed from calendar-date averaged 500-mb heights (1946-1979) to wave amplitudes computed on a daily basis, then averaged by *calendar date irrespective of phase angle.* High values are indicative of interannual persistence, low values of interannual variability. (a) Wave No. 1; (b) Wave No. 2 (Reiter and Westhoff, 1981).

The monsoonal effects of the plateaus come to light from the long-term mean geopotential height distributions characteristic of the planetary boundary layer (PBL). Over the Western Plateau of North America the 850-mb surface provides a good indication of that layer, whereas over Tibet the 600-mb surface is more appropriate. Figures 2a and b show the January pressure patterns of the PBL over the Western United States (Tang and Reiter, 1984) and over Tibet (Gao et al., 1981; Ye et al., 1979). High pressure systems dominate the plateau regions. The resultant wind fields agree well with the details of the pressure distribution. In Figs. 3a and b summer conditions (July) are displayed. Not only do we find the dominance of low-pressure conditions over both plateaus, but there are semipermanent mesoscale features whose impact is felt in the development of convective precipitation systems. Notably, the anticyclonic shear line over Wyoming and Idaho marks the northern extent of the monsoon-related occurrence of severe convection, as could be proven from satellite composite pictures.



Monthly Mean for January (1961-1970)

Fig. 2 (a) Mean 850-mb heights at 1200 GMT in January (solid lines, geopotential decameters) and resultant winds at the surface (if only one arrow is drawn) and at the surface and 850 mb (if two arrows are drawn, the lighter one refers to 850 mb). Velocities indicated as follows: No barb <0.5 m/sec; short barb 0.5-1.4 m/sec; long barb 1.5-2.4 m/sec, etc. Heavy, full lines indicate axes of high pressure, dashed lines of low-pressure systems (Tang and Reiter, 1984). (b) Mean 600-mb contours in January over Asia (dotted: Plateau of Tibet, after Gao et al., 1981 and Ye et al., 1979).



Monthly Mean for July (1961-1970)

Fig. 3 Similar to Fig. 2, but for July.

The layer characterized by a monsoonal wind reversal (>120 degrees between winter and summer) is rather distinct over both plateaus (Figs. 4a and b), but thicker over Tibet than over the United States. The higher elevation of the Plateau of Tibet obviously generates a greater degree of baroclinicity with its surroundings, causing a more vigorous circulation system to establish itself. It should be pointed out that the low-level jet stream of Texas and Oklahoma lies, at least in part, within the domain of the monsoonal plateau influence. It is also dominated by the diurnal plateau circulation, as will be demonstrated later.

The monsoonal plateau effects leave a strong imprint on the seasonal distribution of precipitation. During summer, relatively moist conditions prevail to the south and the east of the plateaus (Figs. 5a and b). Especially along the eastern slopes of the Rocky Mountains a summer precipitation peak is evident (Fig. 6). West of the Rocky Mountains frontal disturbances cause a winter maximum and a more even, annual precipitation distribution. Such a maximum is also evident from Fig. 7a, whereas the January precipitation over Tibet (Fig. 7b) gives the impression of general dryness. The glaciers in the Transhimalaya (Nyainqentanglha Shan) and in eastern Tibet might bring the distribution shown in Fig. 7b and obviously derived from valley stations into dispute.

Neither over the Western Plateau of North America, nor over Tibet can we claim adequate knowledge of the hydrological cycle and of the monsoonal effects upon it. The station network is sparse and

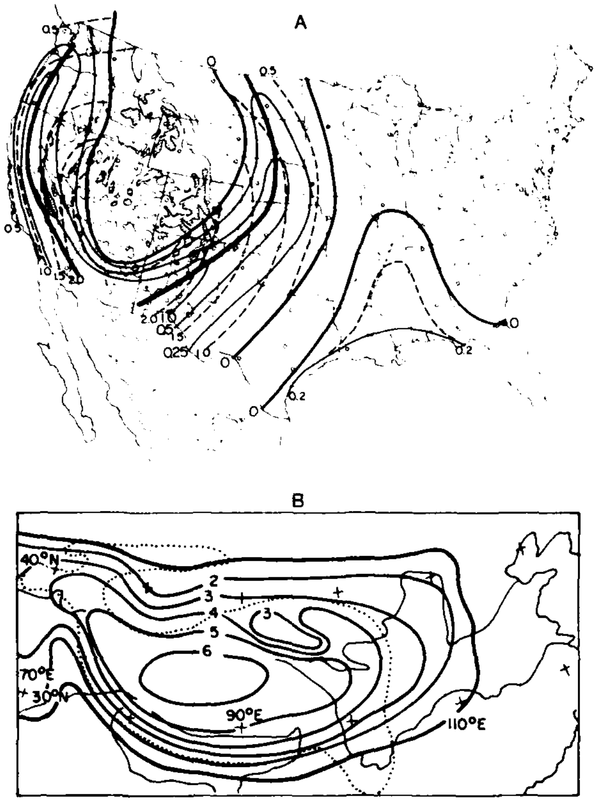


Fig. 4 (a) Dashed lines: height above sea level (km) of the top of the layer with monsoonal wind reversal >120 degrees; full lines: thickness of that layer (km) above terrain. Data for 1200 GMT were used (Tang and Reiter, 1984). (b) Height of top of monsoon layer over Plateau of Tibet. Heavy line delimits the extent of the monsoon region (after Gao et al., 1981).

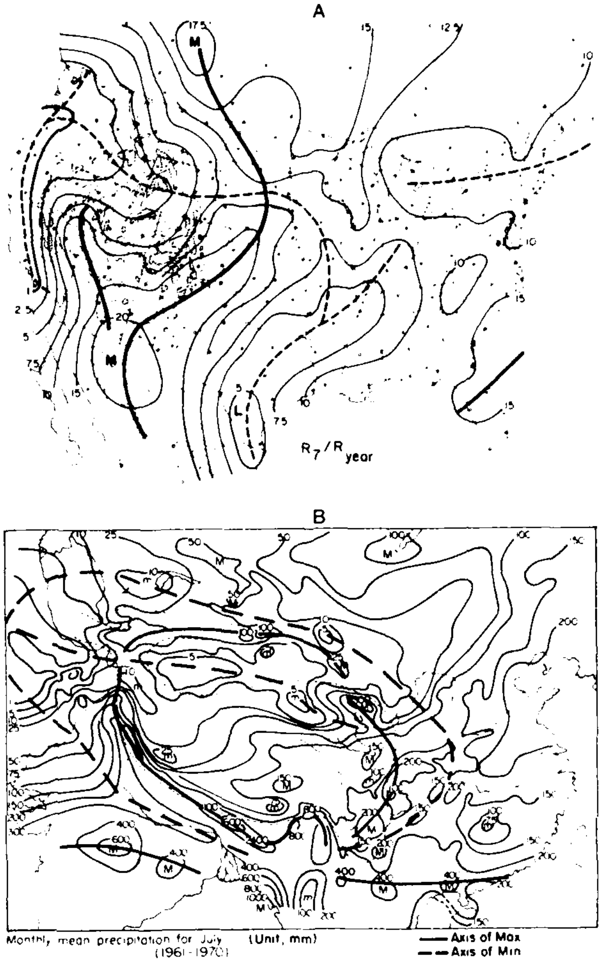


Fig. 5 (a) Ratio of monthly mean July precipitation to annual precipitation over United States (Tang and Reiter, 1984). (b) Monthly mean July precipitation (mm) over Tibet (after Ye et al., 1979).

usually confined to valley locations. Inadequate precipitation estimates, especially over the high mountain ranges, make an assessment of the energy balance of the plateau regions a difficult task.

3. SYNOPTIC AND DIURNAL SYSTEMS.

It stands to reason that synoptic systems impinging on, and traveling over, the large plateau regions suffer drastic modifications. Vortices tend to be modified by the shape of the terrain (Godev, 1971) as well as by the terrain-dependent sensible and latent heat input distributions. Some of these terrain controls become evident in the mesoscale systems that appear even in long-term average presentations of geopotential height fields (Figs. 3a and b). Further evidence of terrain effects comes from the many cases of lee cyclogenesis along the eastern slopes of the Rocky Mountains and of the Tibetan highland, and in the Gulf of Genoa, reported in the literature.

The early detection of lee cyclogenesis presents difficult problems in weather forecasting. Upslope conditions, which usually develop in conjunction with such cyclogenesis, often bring heavy precipitation to relatively confined regions. Timely warnings concerning hazardous weather conditions depend on such early detection and on the correct placement of the incipient cyclone. Especially over Eastern Tibet, where most of the weather stations are located in the deep river gorges, surface wind patterns are strongly controlled by topographic channeling. Surface pressure tendencies at a few stations often provide the only clue of impending cyclogenesis and of potentially heavy precipitation in the sparsely populated mountain regions.

Numerical modeling of synoptic systems in mountainous terrain still suffers from a number of difficulties. As an example, we present the case of

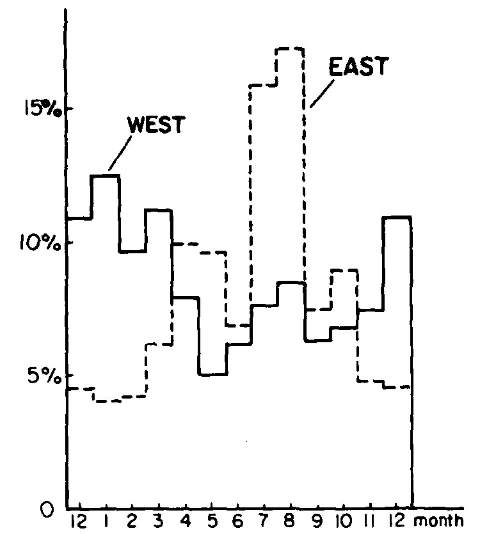


Fig. 6 Monthly precipitation, in percent of annual, at Crested Butte ("west") and Buena Vista ("east"), Colorado (Tang and Reiter, 1984).

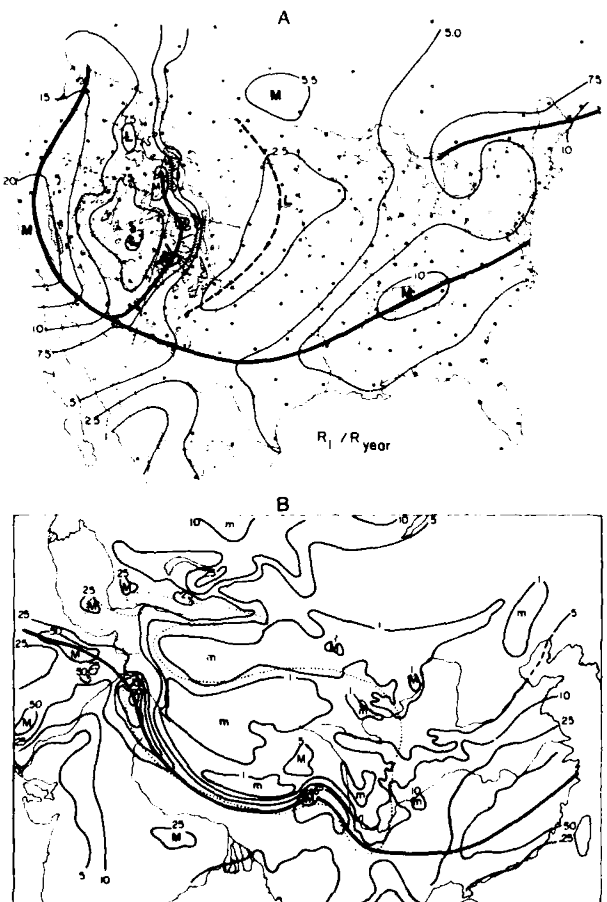


Fig. 7 Similar to Fig. 5, but for January.

Tibetan cyclogenesis of June 8, 1979. A prognostic model, originally developed by Anthes and Warner (1978), was modified to accommodate conditions as encountered over the high plateau. Table 1 contains an overview of the changes which have been made in the original version of the model.

The relatively large domain of the model and the use of a σ-coordinate system necessitated a drastic smoothing of the topographic features used in the model. As Fig. 8 shows, the steep "cliffs" of the Himalayas and Transhimalayas were all but eliminated in the model. Best results were achieved with a reduction of the surface elevations shown in Fig. 8 by a factor of 0.8. In spite of these shortcomings in the assumed terrain characteristics, the model performed reasonably well, leading us to believe that terrain details, in many cases, are not of overriding importance in the development of synoptic-scale systems.

It should be pointed out that our computations did not rely on surface heat fluxes parameterized fro radiation balance considerations, but used the differ ences between air and soil surface temperatures. Th latter are being measured directly at many static locations in China and seem to provide a more accura input for heat flux estimates than the radiatic balance parameterizations. Too many poorly accountec effects enter into the local radiation balances, such as vertical moisture and temperature profiles, cloud and soil conditions, etc., to provide a reliable estimate of soil surface temperatures. Furthermore, we relied on Chinese weather maps, subjectively analyzed, to define the initial conditions of our model run. In earlier work (Reiter and Gao, 1982) we found the objective analyses provided by the U.S. National Meteorological Center (NMC) to be rather inadequate over Tibet. Also, of great importance in the specification of the initial conditions is the inclusion of the observed temperature fields instead of temperature fields obtained from the hydrostatic equation. The use of observed temperatures reduces errors introduced by the hydrostatic equation (Shen, 1983) and prevents the model from "blowing up".

Figures 9 and 10 show sequences of 700-mb wind field and geopotential height prediction, to be compared with the observed wind fields depicted in Fig. 11. It should be noted that, with the exception of the river gorges of Eastern Tibet, this isobaric surface is a figment of modeling. In reality it would lie beneath the ground surface. Nevertheless, the decay of an eastward moving vortex over Tibet, and the subsequent development of another vortex over the river gorge region were predicted with reasonable accuracy by the model. The heavy precipitation predicted by the model may have been an exaggeration (Fig. 12). Had it been used for flood warning, it would have served its purpose, however.

A number of difficulties still remain to be overcome. We already mentioned the inadequate representation of terrain features in the model. Estimates of convective precipitation need further refinement based on atmospheric physics rather than on the fine tuning of assumed vertical profiles of condensation heating. The role of evaporation from the soil may be significant and is not yet treated adequately.

Directly measured soil surface temperatures appear to constitute an improvement over parametericaly derived values. Such temperatures are not measured in the United States and in Western Europe.

Table 1 Comparison between Anthes and CSU mesoscale models.

	Anthes et al., 1982	C.S.U., Shen 1984
Input Data	LFM First Guess, Enhanced by Surface and Significant Level Data	Gridded Values From Subjectively Analyzed Fields
Initialization	Remove the Vertical Integral of Divergence	None
Delta s	90 km	96 km
Delta t	191 s	180 s
Horizontal Domain	41 x 41	31 x 41
Horizontal Grid Structure	Lambert Conformal, Staggered "B" Grid	Mercator, Nonstaggered Grid
Vertical Layers	10	6
Vertical Coordinate	Sigma - P	Sigma
Spatial Finite Difference	2nd Order	2nd Order
Temporal Finite Difference	Brown-Campana, Time Filter	Euler and Central
Lateral Boundary Condition	Time-Dependent, From Observations	Fixed
Terrain	Yes	Yes
Surface Heat Flux	Over Water Only	Over Land
Surface Evaporation	Over Water Only	Over Land
PBL (Including Surface Layer)	Bulk, $1.5\times10^{-3} < CD < 2.0\times10^{(-3)}$	Bulk, $(CD=(1+0.0001\ \phi^*)\times 10^{(-3)})$
Shortwave Radiation	No	Incl. in Sfc. Heat Flux
Longwave Radiation	No	T^* - Ta
Convective Clouds & Precipitation	Kuo-Type (Anthes, 1977)	Kuo
Nonconvective Clouds & Precipitation	Saturation Criterion 100%	Upward Motion and 80% Saturation
Horizontal Internal Mixing	K $(\mathrm{Del})^4$	K prop. U,V; K $(\mathrm{Del})^4$ T, Q
Vertical (Above PBL) Mixing	None	Yes
Computer Time for 24 h Forecast	6.6 Min on Cray-1A	3 Min on Cray-1A

ϕ^* = geopotential = $(g\cdot z)$
z = height above sea level
T^* = ground surface temperature

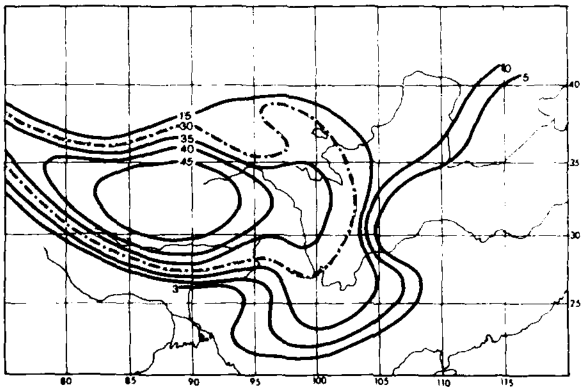


Fig. 8 Terrain height, in hundreds of meters, used in numerical model.

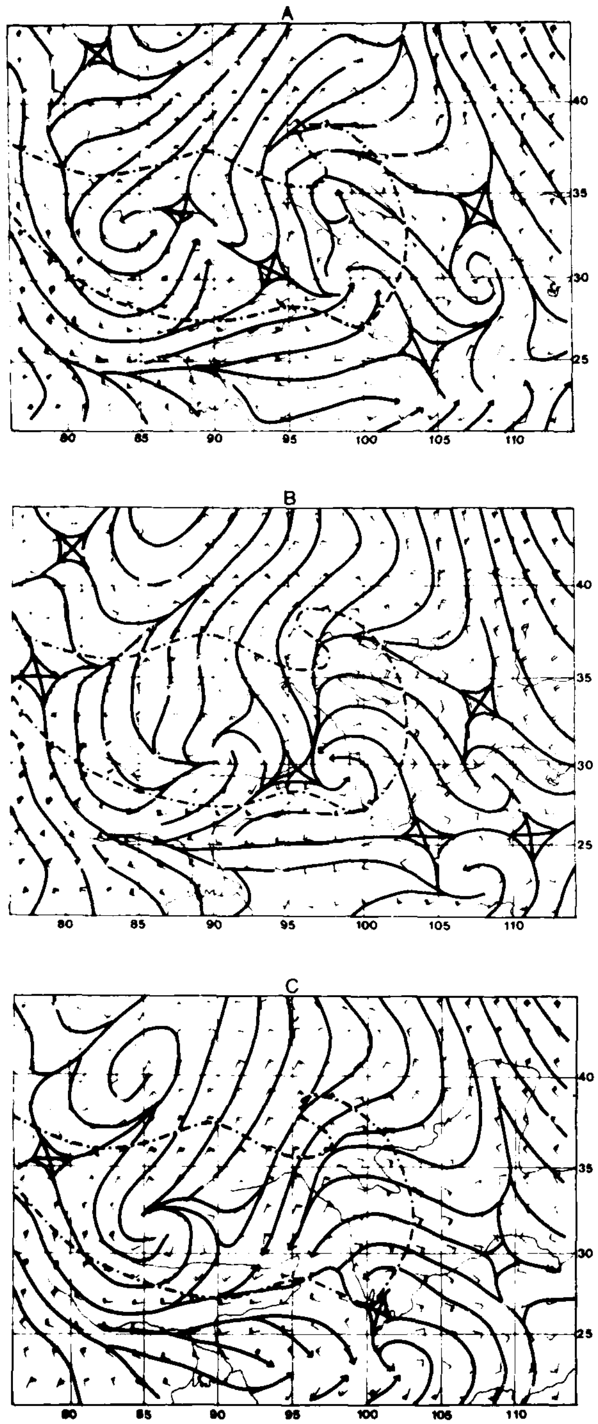


Fig. 9 Model predictions of 700-mb wind field. (a) 6-hour forecast, verifying 1800 GMT, June 8, 1979. (b) 12-hour forecast, verifying 0000 GMT, June 9, 1979. (c) 24-hour forecast, verifying 1200 GMT, June 9, 1979.

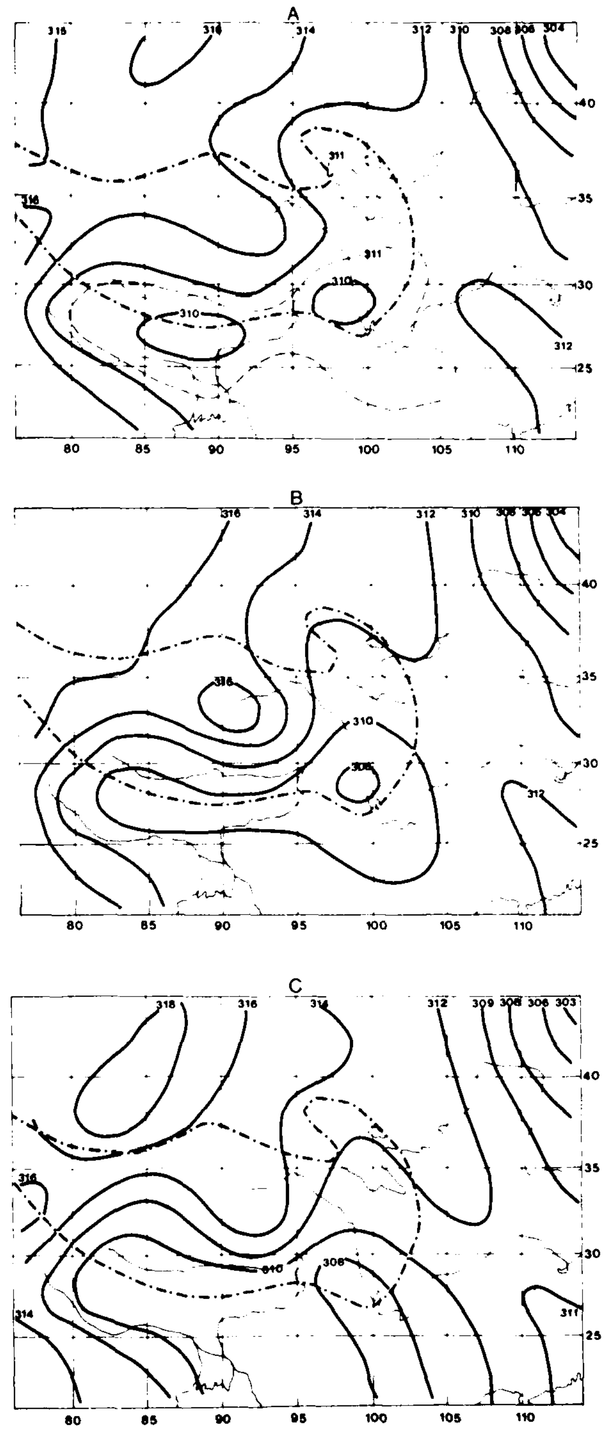


Fig. 10 Model predictions of 700-mb geopotential heights for same validation times as in Fig. 9.

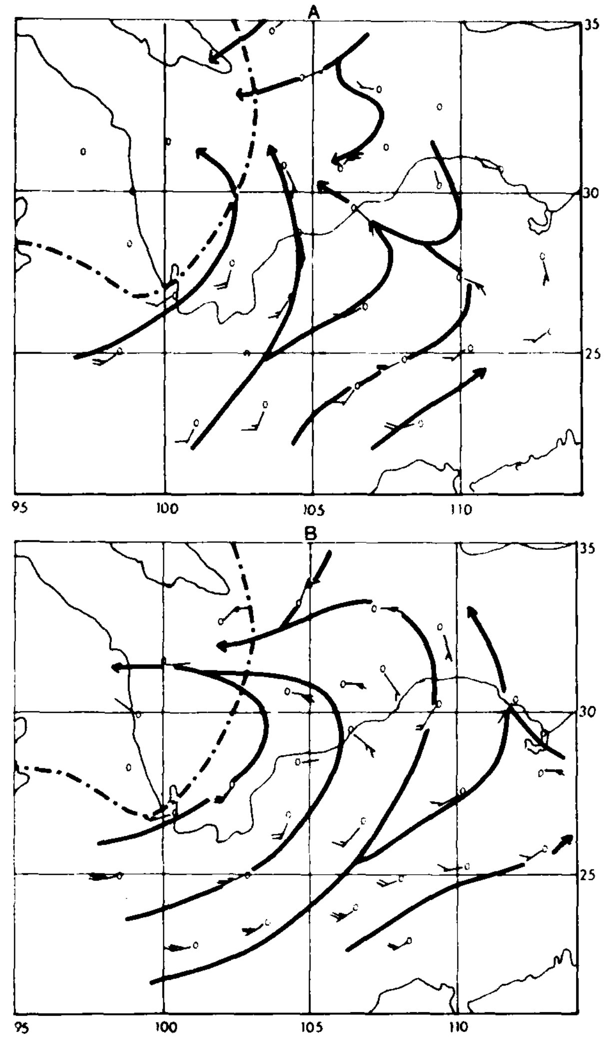


Fig. 11 Observed 700-mb streamlines (a) 0000 GMT, June 9, 1979; (b) 1200 GMT, June 9, 1979.

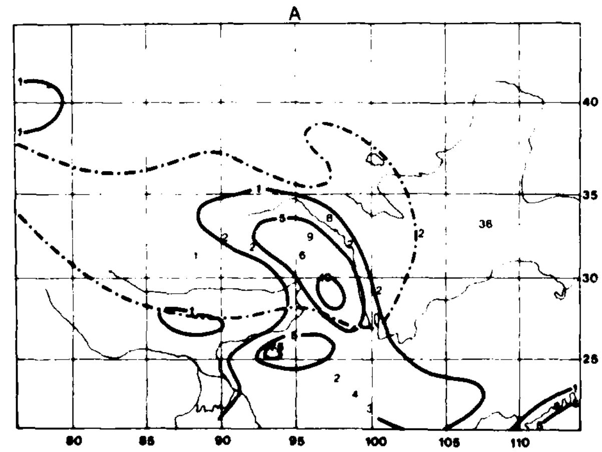


Fig. 12 Predicted (contour lines, mm) and observed (numerical values, mm) precipitation. (a) 6-hour period, ending at 1800 GMT, June 8, 1979. (b) 12-hour period, ending at 0000 GMT, June 9, 1979. (c) 6-hour period, ending at 1200 GMT, June 9, 1979.

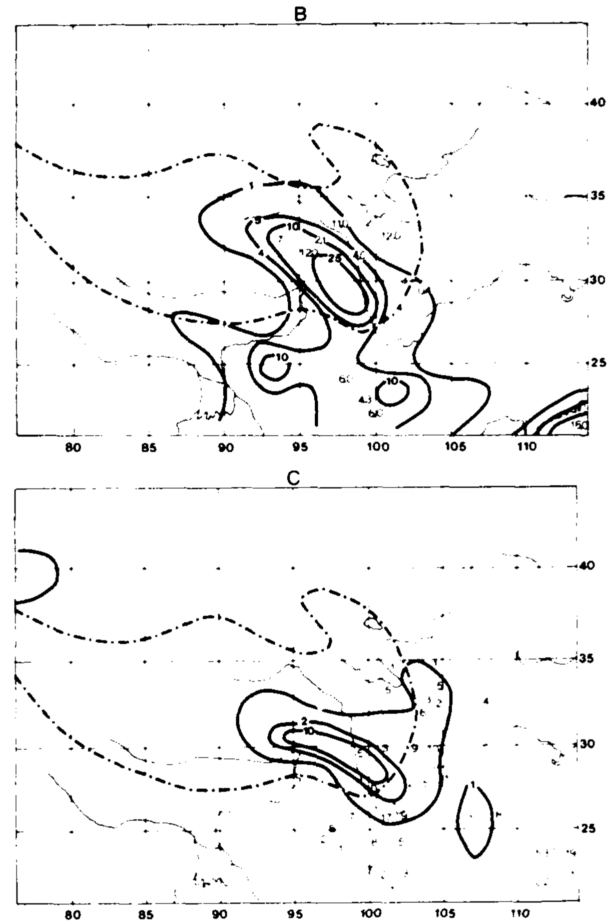


Fig. 12 (Continued)

Chinese measurements rely on a large-bulb thermometer, with half of the bulb buried in soil. One may criticize this method of measurement. It is, however, inexpensive and seems to be effective and might warrant imitation by weather services in other countries.

Diurnal surface heating variations were included in our model run by first estimating the daily average temperature differences between air and ground at each grid point from direct observations made at synoptic stations four times a day. Then a sinusoidal, diurnal variation with twice the amount of the mean difference reached at noon, and zero difference reached at midnight was assumed. Thus, in our model the soil surface temperatures never fell below the air temperatures. As more detailed topographic features are modeled, we will have to change these assumptions on diurnal heating variability in order to allow valleys to fill with cold air at night and develop inversion layers. With the present model configuration such refinements, most likely, would be counterproductive "overkill".

That diurnal variability in heating effects plays an important role over mountainous terrain comes to light in diagnostic studies. Reiter and Tang (1984) analyzed the long-term mean surface flow and 850-mb geopotential height patterns over the Western Plateau of North America at three-hour intervals for July. The examples for 0200 and 1400 Mountain Standard Time

are shown in Figs. 13a and b. Also indicated in Fig. 13a are the stations with and without a diurnally reversing valley wind system. The 850-mb height patterns were obtained from an extrapolation equation which relies on surface pressures and temperatures.

According to the study by Reiter and Tang the greatest diurnal variation exists along the Continental Divide of the Rocky Mountains of Colorado and New Mexico. They also found that surface pressure records of stations in the plains to the east of the Rocky Mountains show a distinct, semidiurnal pressure wave, whereas at stations over the plateau such a wave is suppressed and overshadowed completely by the effects of the diurnal heating and cooling cycle on the surface pressure distribution.

The Tibetan highland, according to data presented by Gao et al. (1981), also reveals a diurnal variability in 600-mb heights (Fig. 14). Because of the evening and morning hours of local time which coincide with the 0000 and 1200 GMT observation periods, the diurnal variability is not expressed as sharply in the Tibetan sample as it is in the U.S. sample described above.

From Fig. 13 it appears as though the Texas low-level jet streams were embedded in southerly flow with only little diurnal variation. A different picture emerges, however, if one analyzes three-hour geopotential height variations and vector differences in resultant winds. As an example, we present the mean geopotential height changes in July from 1100 to 1400 MST and from 2300 to 0200 MST, together with the appropriate, three-hour vectorial changes in the resultant winds of these observation times (Fig. 15a, b). A clear, diurnal reversal in the plateau effects on the wind systems over the plains to the east of the Rocky Mountains can be seen. Thus, it appears that the Texas LLJ is not only part of the monsoon flow system described in the preceding chapter which causes a broad, southerly flow during summer, but it is strongly modulated by diurnal plateau effects and therefore becomes also a part of a gigantic "plateau circulation system".

This system reverses itself from day to night. It is superimposed upon monsoonal- and synoptic-scale flow patterns. Because it generates its own divergence and convergence fields, we have to assume that it carries a significant impact on regional precipitation regimes. Such impact is brought to light in Fig. 16 which depicts the local time of maximum occurrence of thunderstorm activity. We see that in the regions in which major heat islands develop over the plateau during the daytime, thunderstorm frequency is highest in the early afternoon ("E"). As the plateau circulation system reverses in the late afternoon and evening, a belt of convergence surrounding the plateau is generated, causing the thunderstorm activity to maximize around midnight over the plains to the east of the mountains ("L").

Similar conditions, although not yet analyzed in the same fashion, appear to occur over, and to the east of, Tibet Over the plateau convective activity and hailfall tends to favor the afternoon hours, whereas over Sichuan Province nighttime thunderstorms and convection are a frequent occurrence.

Sang and Reiter (1982) successfully modeled such a "plateau circulation system" over an idealized plateau. The horizontal dimensions obtained for such a system in the model agreed well with those observed in nature.

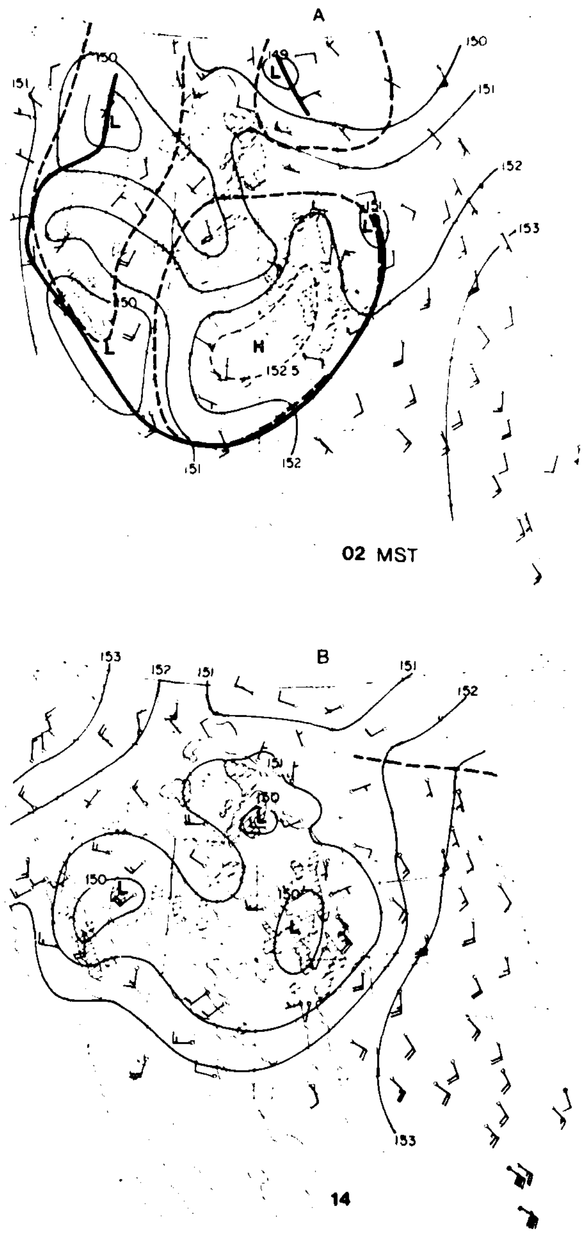


Fig. 13 Mean 850-mb heights (geopotential decameters) in July at (a) 0200 MST (0900 GMT) and (b) 1400 MST (2100 GMT). Resultant winds are symbolized as in Fig. 2. Trough is indicated by heavy solid line. Stations marked "x" show no diurnal wind reversal, stations with "v" do. Dashed line in Fig. 8 delimits the extent of the regions with diurnal valley-mountain breeze systems (Reiter and Tang, 1984). Terrain above 2750 m is hatched.

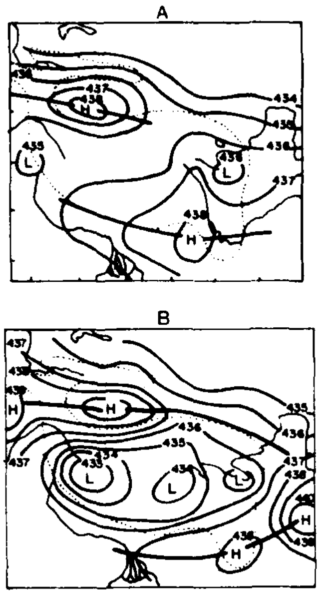


Fig. 14 600-mb heights (geopotential decameters) for (a) 0000 GMT and (b) 1200 GMT over Tibet (Ye et al., 1979).

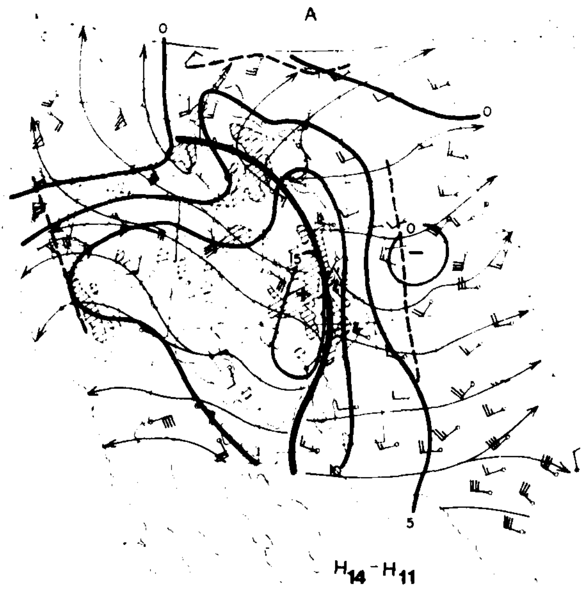


Fig. 15 Mean three-hour changes of the 850-mb surface in July (geopotential meters, solid lines of *medium thickness*), *three-hour* changes of resultant winds (barb notation is exaggerated by a factor of five over explanation given in Fig. 2), and "streamlines" of these vector changes (thin, solid lines). Axes of cyclogenetic (convergent) and anticyclogenetic (divergent) centers are indicated by heavy dashed and solid lines, respectively. (a) 1400 MTS minus 1100 MST, (b) 2300 MST minus 2000 MST (Reiter and Tang, 1984).

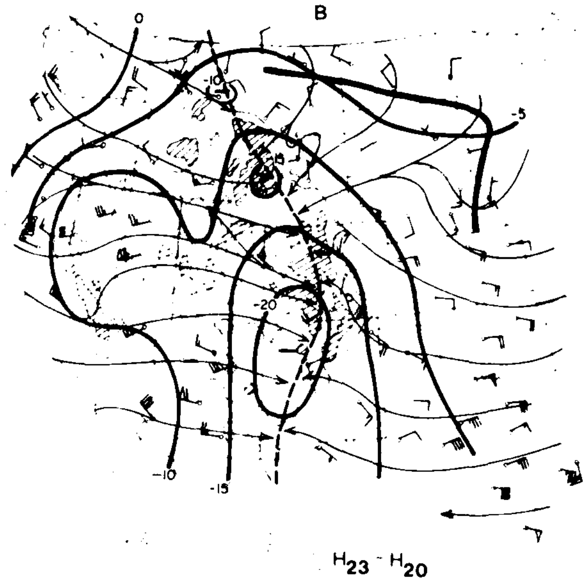


Fig. 15 *(Continued)*

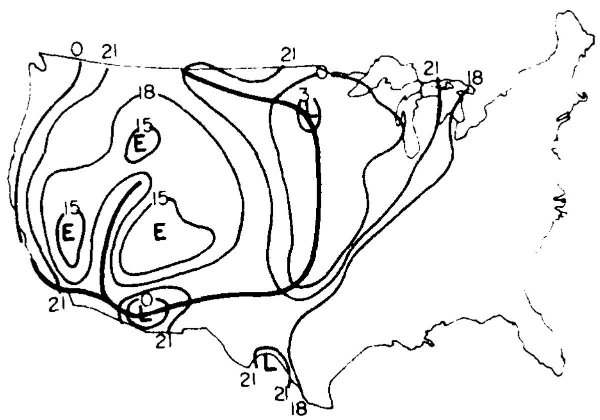


Fig. 16 Local time of day of maximum frequency of thunderstorm occurrance. E = early, L = late. (Reiter and Tang, 1984; data from Wallace, 1975.)

4. LOCAL CIRCULATION SYSTEMS.

If the surface and atmospheric energy budget differences between plateaus and surrounding plains appear to drive the diurnal plateau circulation systems, we have to assume that, *on a smaller scale*, similar principles are active in generating local mountain and valley breeze systems. Such assumptions underlie most of the presently used two- and three-dimensional, small-scale models [see e.g. Pielke and Mahrer (1975), Whitemen and McKee (1982)].

Under idealized circumstances valley breezes interact with slope wind systems as the sunlit mountains heat up. Mountain breezes set in with cooling in the evening and during the night. In nature,

however, conditions rarely are as simple as that. From the foregoing discussion we have to assume that horizontal pressure gradients, caused by differential heating of plateaus by monsoonal and diurnal effects, modulated by synoptic disturbances, will interact with the local effects of heat source distributions.

As an example of such an assumed interaction we show in Fig. 17 the diurnal variability of resultant winds for July, indicated by speed and direction, for Denver and Colorado Springs, Colorado. These two stations lie only about 100 km from each other. Both are to the east of the Continental Divide. Whereas Denver reveals a wind oscillation between southwest and northeast, conforming to the orientation of the South Platte River valley, the diurnal wind variation in Colorado Springs to the south of Denver appears to be strongly affected by a low ridge of hills to the north of the station (the Palmer Ridge). Both stations lie within the domain of the plateau circulation of the eastern slopes of the Rocky Mountains, described in the preceding chapter. The rather low Palmer Ridge, however, provides a significant, local perturbation which is superimposed on the larger-scale plateau wind system.

From Fig. 17 one can see that convergence between the flow to the north (Denver) and to the south (Colorado Springs) of the Palmer Ridge dominates the daytime hours and maximizes during the early afternoon. At night divergent flow conditions prevail. Thus, the Palmer Ridge, insignificant as its elevation may be in comparison to the towering Rocky Mountains rising only a short distance to the west, becomes a significant, local focal area for thunderstorm development. The regional fauna attests to the fact: *The "Black Forest" to the north of Colorado Springs* stretches a "finger" of forest land eastward into the surrounding, treeless plains.

5. CONCLUSIONS.

The foregoing discussion provided enough evidence for the profound effects of plateaus on circulation systems of all scales. Most of this evidence had to be compiled by patient work with insufficient data. The harsh mountain environment usually is characterized by the absence of population centers, hence by the absence of weather stations with sufficiently long records to allow meaningful analyses. Most of our analysis work, therefore, is heavily biased towards conditions unrepresentative of the real mountain environment. Unfortunately, such biases are carried over into the initialization of numerical models and into the verification of their veracity.

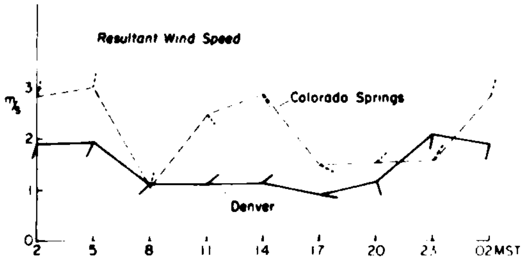


Fig. 17 Mean diurnal variation of resultant wind speed (m/sec) and direction at Colorado Springs and Denver, Colorado, for July (Reiter and Tang, 1984).

The critical assessment of the state of the art of mountain meteorology calls for a commitment to measurement programs which will provide better data from regions not normally serviced by routine observations.

REFERENCES

Anthes, R.A., 1977: A cumulus parameterization scheme utilizing a one-dimensional cloud model. Mon. Wea. Rev., 105, 270-286.

_____ and T.T. Warner, 1978: Development of hydrodynamic models suitable for air pollution and other mesometeorological studies. Mon. Wea. Rev., 106, 1045-1978.

Chen, L.T. and Z.X. Yan, 1978: A statistical analysis of the influence of anomalous snow cover over Qinghai-Tibetan Plateau during the winter-spring on the monsoon of early summer (in Chinese). Proceedings of the Conference on Medium and Long-Term Hydrometeorological Prediction in the Basin of the Yangzi River. May 1978, Vol. I, Hydro-Electric Press, Beijing.

Gao, Y.X., M.C. Tang, S.W. Luo, Z.B. Shen and C. Li, 1981: Some aspects of recent research on the Qinghai-Xizang Plateau meteorology. Bull. Amer. Meteor. Soc., 62 (1), 31-35.

Godev, N., 1971: Anticyclonic activity over Southern Europe and its relationship to orography. J. Appl. Meteor., 10, 1097-1102.

Hahn, D.G. and J. Shukla, 1976: An apparent relationship between Eurasian snow cover and Indian monsoon rainfall. J. Atmos. Sci., 33 (12), 2461-2462

Hanna, A.F., D.E. Stevens and E.R. Reiter, 1984: Short-term climatic fluctuations forced by thermal anomalies. J. Atmos. Sci., 41 (1), 122-141.

Julian, P.R. and Chervin, R.M., 1978: A study of southern oscillation and Walker circulation phenomenon. Mon. Wea. Rev., 106, 1433-1451.

Pielke, R.A. and Y. Mahrer, 1975: Representation of the heated planetary boundary layer in mesoscale models with coarse vertical resolution. J. Atmos. Sci, 32 (12), 2288-2308.

Reiter, E.R., 1982: Typical low-tropospheric pressure distributions over and around the Plateau of Tibet. Arch. Met. Geoph. Biokl., Ser. A, 31, 323-327.

_____ and Y.-H Ding, 1980/81: The role of Qinghai-Xizang Plateau in feedback mechanisms affecting the planetary circulation. Scientia Atmospherica Sinica, 4 (4), 300-309, 5 (1), 9-22.

_____ and D.R. Westhoff, 1981: A planetary wave climatology. J. Atmos. Sci., 38 (4), 732-750.

_____ and Deng-yi Gao, 1982: Heating of the Tibet Plateau and movements of the South Asian high during spring. Mon. Wea. Rev., 110 (11), 1694-1711.

_____ and Maocang Tang, 1984: Plateau effects on diurnal circulation patterns. Accepted, Mon. Wea. Rev.

Sang, Jianguo and E.R. Reiter, 1982: Model-derived effects of large-scale diurnal thermal forcing on meteorological fields. Arch. Geoph. Biokl., Ser. A, 31 (3), 185-203.

Shen, Rujin, 1983: The rationality of the initialization of temperature and the calculation of pressure gradient term. Scientia Atmospherica Sinica, 7 (2), 189-200.

Tang, Maocang and Elmar R. Reiter, 1984: Plateau monsoons of the Northern Hemisphere: A comparison between North America and Tibet. Accepted, Mon. Wea. Rev.

Wallace, J.M., 1975: Diurnal variations in precipitation and thunderstorm frequency over the conterminous United States. Mon. Wea. Rev., 103, 406-419.

Whiteman, C.D. and T.B. McKee, 1982: Breakup of temperature inversions in deep mountain valleys: Part II. Thermodynamic model. J. Appl. Met., 21, 290-302.

Ye, D.Zh., 1982: Some aspects of the thermal influences of the Qinghai-Tibetan Plateau on the atmospheric circulation. Arch. Met. Geoph. Biokl., Ser. A, 31, 205-220.

_____, Y.X. Gao, M.C. Tang, S.W. Lo, C.B. Shen, D.Y. Gao, Z.S. Song, Y.F. Qian, F.M. Yuan, G.Q. Li, Y.H. Ding, Z.T. Chen, M.Y. Zhou, K.J. Yang, and Q.Q. Wang, 1979: Meteorology of Qinghai-Xizang (Tibet) Plateau. Science Press, Beijing (in Chinese).

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Tibetan Plateau
Western Plateau-N. America

Environmental Research Paper No. 37
March 1984, 12 pp.

NSF, Grant ATM 83-13270; United States Air Force, AFOSR 82-0162; NASA Grant NAGW-601

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